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THE EFFECT OF COOLING RATE ON THE APPARENT BOND STRENGTH OF POR--ETC(U)  
MAR 81 J W GUINN, W H GRISWOLD, S G VERMILYEA

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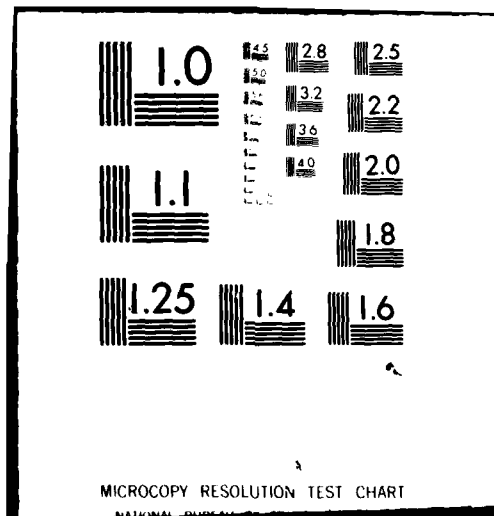
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The effect of cooling rate on the apparent bond strength of porcelain-metal couples

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Commercial materials and equipment are identified in this report to specify the experimental procedure. Such identification does not imply official recommendation or endorsement or that the materials and equipment are necessarily the best available for the purpose. Furthermore, the opinions expressed herein are those of the authors and are not to be construed as those of the Army Medical Department.

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Ceramo-metal restorations comprise a substantial percentage of the fixed prosthetic devices provided for patients by modern restorative dentistry. Dental porcelain when fused to a metal substructure, provides acceptable esthetics and improved strength to resist occlusal forces above that afforded by porcelain used singly. However, catastrophic failures, whether cohesive within the porcelain or adhesive at the porcelain-metal phase boundary are not infrequent occurrences. Clinically, such failures usually occur after cementation of the restoration. It is possible, however, that the failure occurs during the laboratory phase of restoration fabrication and becomes clinically manifest with manipulative forces generated at the time of or subsequent to the cementation procedure.

Controversy exists as to the causes of the failure of the porcelain-metal couple. One study has suggested that the rate of cooling of the porcelain-metal composite from the fusion temperature of the ceramic component may generate shear stresses sufficient to adversely affect the apparent porcelain-metal bond strength.<sup>1</sup> Furthermore, residual phase boundary stresses subsequent to fusion of the porcelain depend largely upon the thermal history of the porcelain-metal couple.<sup>2</sup> It has been suggested that controlled rates of cooling may enhance the strength of the porcelain-metal bond.<sup>1,3</sup> Several texts<sup>4,6</sup> recommend specifically that ceramo-metal restorations be cooled under a glass cover following removal from the firing oven, whereas others advocate cooling of the restoration in ambient air.<sup>7</sup> Conversely, some investigators have suggested that the surface of the restoration be cooled rapidly to provide a tempered glass effect.<sup>3,8</sup> Clearly, selection of techniques for the cooling of ceramo-metal restorations appears arbitrary and an analysis of the affects of cooling rate on the porcelain-

metal bond may provide criteria for selection of a specific technique.

The objectives of the present study were to determine the effects of cooling rate on the apparent strength of the porcelain to metal bond, and if possible, recommend a technique for the cooling of ceramo-metal restorations immediately following the firing procedure.

#### MATERIALS AND METHODS

A high fusing gold-palladium-silver casting alloy\* and an opaque dental porcelain+ commonly employed in the fabrication of ceramo-metal restorations were used in this investigation.

Metal discs (1/4 X 1/16 inch) were fabricated by conventional laboratory procedures. Wax patterns were formed in stainless steel molds and invested in a phosphate bonded refractory material.# The resultant molds were placed in a cold oven, heated to 1300° F and held at temperature for one hour to insure complete wax elimination. Melting and casting of the alloy was accomplished with the aid of a gas-oxygen-torch and a centrifugal casting machine.§ The alloy-laden molds were allowed to cool to room temperature and the castings divested from the refractory. The sprues were removed and the surfaces of the cast discs were finished on 240-grit metallographic paper, cleaned ultrasonically in distilled water and dried in air. The discs were then heated in an oven¶ to 1945° F, held at

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\*Cameo, J. F. Jelenko and Co., New Rochelle, NY, 10801.

+B. F. Vacuum Porcelain (Paint-O-Pake), Ceramoc Inc., New York, NY, 11101.

#Complete, J. F. Jelenko and Co., New Rochelle, NY, 10801.

§Centrifugo Casting Machine, Kerr Manufacturing Co., Detroit, MI 48218.

¶Ney Mark IV Digital; J. M. Ney Co., Barkmeyer Division, Yucaipa, CA 92399.

temperature for two minutes and allow to cool to room temperature in ambient air prior to further handling.

The test method for the determination of apparent alloy-porcelain bond strength was that described by Civjan et al.<sup>9</sup> Porcelain cylinders (1/8 X 1/2 inch) were formed in paper tubes affixed perpendicular to the surface of the cast discs. The porcelain was mixed with distilled water and the resultant slurry vibrated into the tubes. The excess liquid was extracted by capillary action into tissue paper. The porcelain-metal specimens were placed in an oven at 1100° F until combustion of the paper tubes was complete. Then the specimens were subjected to the following porcelain firing cycle:

- a) heating from 1100° F to 1725° F at 100° F per minute under vacuum.  
The vacuum was released at a temperature of 1725° F and the specimens heated to 1775° F;
- b) heating from 1100° F to 1675° F at 100° F per minute under vacuum.  
The vacuum was released at a temperature of 1675° F and the specimens heated to 1775° F;
- c) reheating as in step (b); and
- d) heating from 1100° F to 1800° F at 100° F per minute without vacuum.

After each step of the cycle the specimens were cooled from the firing temperature to room temperature under one of the following conditions:

- a) in ambient air,
- b) under a ceramic cover,
- c) within the oven to 1200° F, then in ambient air,
- d) atop an aluminum heat sink,\*\*

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\*\*Ceramco FAS-COOL, Ceramco, Inc., New York, NY 11101.

e) with forced air, or

f) within an ice chest.

The ceramic portions of each porcelain-metal couple were embedded in a 9/16-inch cube of a commercially available tray acrylic.<sup>++</sup> Each cube was mounted in an aluminum fixture for added support. The entire assembly was then oriented on a constant displacement rate testing machine<sup>##</sup> to permit loading of the discs in a diametral (shearing) direction (Figure). Each sample was loaded at a crosshead descent rate of 0.02 inch per minute. The strength of the porcelain-metal bond was calculated on the basis of ultimate load at shear failure per unit area of apparent porcelain metal contact. A total of 60 specimens were fabricated. Ten-specimen-lots were subjected to each of the six cooling conditions. Specimens exhibiting failure within the porcelain cylinder distant from the porcelain-alloy phase boundary were discarded. Furthermore, to minimize the effects of operator variability in specimen preparation, only the five highest apparent bond strength values for each cooling condition were included in the data analysis. These values of apparent porcelain-metal bond strength were analyzed statistically by analysis of variance and means compared using Scheffe's' method at the five percent level of significance.

## RESULTS

The apparent porcelain-metal bond strength of specimens subjected to

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<sup>++</sup>Fastray, Harry J. Bosworth Co., Skokie, IL 60076.

<sup>##</sup>Instron Universal Testing Machine, Instron Engineering Corp.,  
Canton, MA 02021.



the six cooling conditions are shown in the Table. The range of apparent bond strength values was delineated by specimens subjected to oven cooling (6700 psi) and those cooled in ambient air (4400 psi). Bond strength values for oven cooled specimens were statistically equivalent to those obtained from specimens subjected to cooling in an ice chest but statistically different ( $p < 0.05$ ) from those obtained with other cooling techniques.

#### DISCUSSION

The strength of the bond between the ceramic and metallic components of a porcelain-metal restoration is affected by many factors. The specific porcelain-alloy combination; porcelain condensation technique; amount and distribution of porosity in the porcelain; firing rate; residual stress distribution at the porcelain-alloy phase boundary and the cooling rate of the porcelain-alloy composite from the porcelain maturation temperature to room temperature all contribute to the integrity of the porcelain-alloy bond.

Analysis of the available data suggest that slow-cooling of ceramometal restorations in an oven to 1200° F prior to removal or rapid cooling in an ice chest promote realization of a stronger bond between the two components. However, these techniques may adversely affect the porcelain. Although oven cooling may provide improved mechanical characteristics with age-hardenable alloys, this technique has the potential to result in overfusing of the porcelain.<sup>10</sup> Furthermore, consideration must be given to the large amount of oven time required for the oven cooling technique. This would appear impractical in a busy laboratory.

Conversely, rapid cooling methods have been shown to markedly increase the incidence of checking of the porcelain surface.<sup>11</sup> The lack of a significantly higher bond strength value from specimens subjected to rapid cooling in an ice chest and the increased risk of damage to the porcelain surface would contraindicate the routine use of this technique. Furthermore, a relatively rapid "quenching" may adversely affect the mechanical properties of the alloy.

From a practical point of view, it would appear that cooling of ceramometal restorations under a protective cover would provide the best compromise of high bond strength, sufficient heat treatment of an age hardenable casting alloy and reduced incidence of adverse effects on the ceramic component of the restoration. Although statistically higher apparent bond strengths were obtained from specimens subjected to oven cooling, the difference may not be significant clinically. Furthermore, the additional protection against uneven surface cooling of the porcelain by ambient air currents and the reduced risk of surface checking afforded by the use of a cover suggests that this technique should be used in lieu of a heat sink, forced air or ambient air.

Understandably, caution must be exercised in the extrapolation of data from the present investigation to other porcelain-alloy combinations. The use of specific cooling techniques subsequent to fusion of a particular dental porcelain to a specific substrate metal may be unwarranted. However, unless the effects of uncontrolled cooling of a specific porcelain-metal composite are known, prudent procedure would dictate the use of cooling methods providing the lowest risk both to the integrity and strength of the porcelain-alloy bond and to the surface of the porcelain.

## SUMMARY

The effects of cooling conditions on the apparent bond strength of a dental porcelain fused to a cast substructure were studied. Under the conditions of this investigation, slow cooling of the porcelain-metal composite in an oven or rapid cooling in an ice chest from the maturation temperature of the porcelain resulted in the highest values of apparent bond strength. However, additional factors must be considered in the selection of a particular cooling method. From the present data, it would appear that cooling of a ceramo-metal restoration under a protective cover would provide the least risk to the integrity of the porcelain-alloy bond and to the surface of the porcelain.

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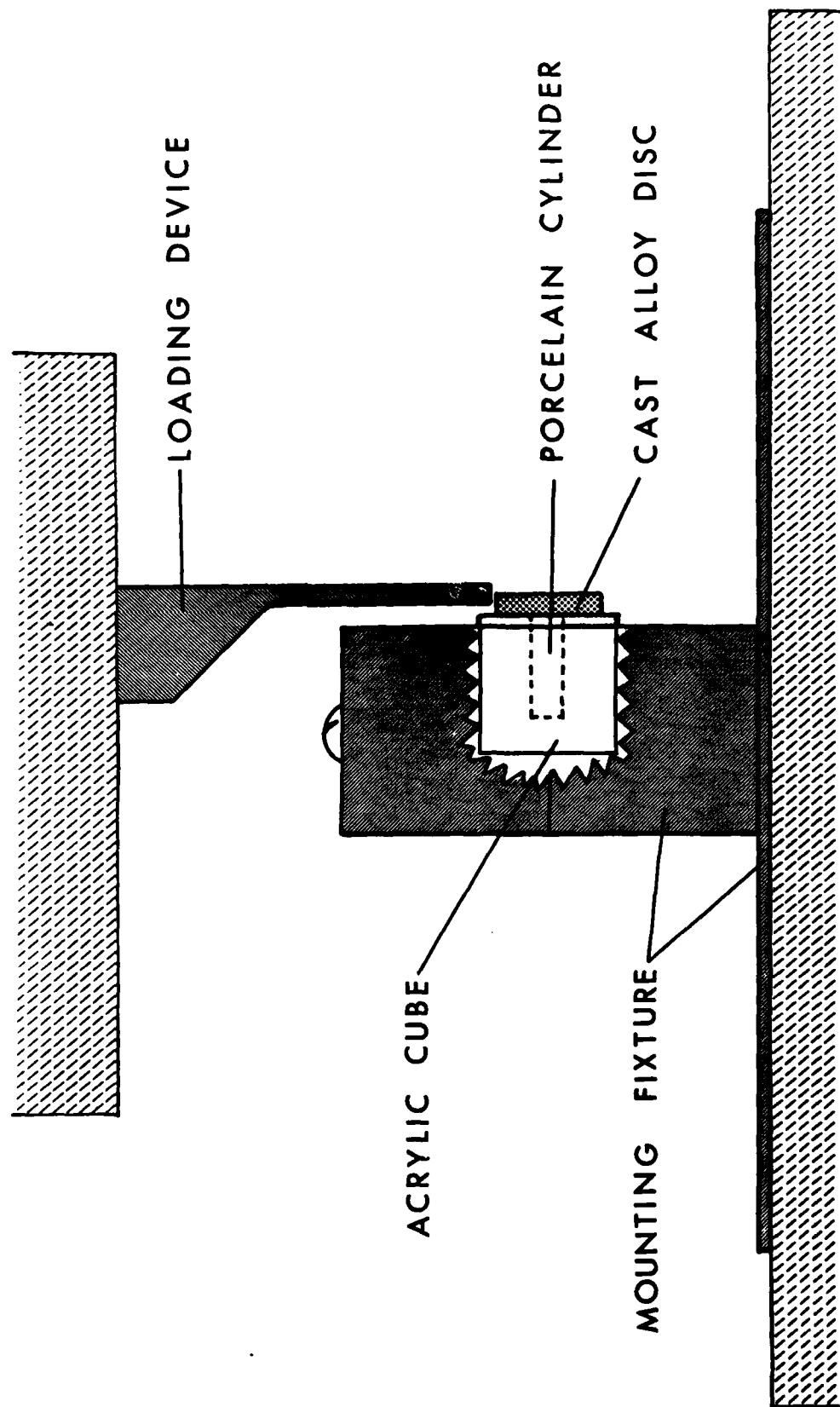
Table. Apparent porcelain-alloy bond strength of five specimens from each cooling method.

Method	Apparent Bond Strength $\bar{x} \pm SD$ (psi)
Oven	6700 $\pm$ 700 *
Ice chest	5600 $\pm$ 700
Under cover	5200 $\pm$ 400
Atop a heat sink	5000 $\pm$ 900
Forced air	4700 $\pm$ 300
Ambient air	4400 $\pm$ 300

\*Mean value  $\pm$  standard deviation (pounds per square inch). The Scheffe' allowance was computed to be 1400 psi at the 5% level of significance.

LEGEND FOR FIGURE

Cross-sectional diagram of the prepared specimen, mounting fixture and loading assembly employed during porcelain-alloy bond strength determination.



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